Changes in the masticatory cycle following treatment of posterior unilateral crossbite in children

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In a previous study, we established that young children with unilateral posterior crossbite have a longer mandibular ramus and more superiorly and posteriorly positioned condyles on the crossbite side. In this study, we evaluated chewing cycle shape and duration in 14 of the patients before treatment, and we looked for changes in cycle shape and duration 6 months after treatment with rapid palatal expansion. Mandibular kinematics was recorded while chewing gum using an optoelectric recording system at 100 Hz. Subjects were asked to chew normally for 20 cycles, chew on the crossbite side only for 20 cycles, and chew on the noncrossbite side only for 20 cycles. A special computer program selected the 10 most representative cycles from each series and computed an average duration and an average maximum excursion along 3 orthogonal axes. Multilevel linear models were used to generate an 8th-order polynomial describing average cycle shape and to test for statistically significant differences in shape between the patients and the controls and between the patients before and after treatment. Before treatment, the patients chewed more slowly than did the controls. Treatment shortened their cycle duration to equal control values. Before treatment, the patients also had larger maximum excursions than did the controls and exhibited a reverse-sequence cycle shape when chewing on the crossbite side. Treatment did not alter the patients' abnormal cycle shape. These results suggest that some features of the masticatory kinematics respond to orthodontic treatment alone, but others do not. (Am J Orthod Dentofacial Orthop 2001;120:521-9)

osterior unilateral crossbite first appears between 19 months and 5 years of age. 1 Reported incidences range between 5.9% and 9.4% of the population, and approximately 67% to 79% of patients with crossbites have dental interferences that produce functional shifts toward the crossbite side on closure.²⁻⁵

Two studies have predicted skeletal asymmetry based on limited resolution of the midline shift with treatment and maintenance of the subdivision malocclusion following treatment.^{6,7} Although morphological asymmetry has been established in adult crossbite patients, there is little information concerning children with functional crossbites. Santos Pinto et al⁸ showed

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moved the crossbite side closer to the midline. Tomographic analyses in this same study showed that the crossbite condyle was positioned significantly more superiorly and posteriorly in the fossa than was the noncrossbite condyle. During the movements from centric relation to maximum intercuspal position, opening, and protrusion, the crossbite condyle tended to move farther than the noncrossbite condyle. During contralateral excursion, the crossbite condyle moved

Posterior crossbite has also been related to deviation in the masticatory chewing pattern. Ahlgren⁹ found the chopping masticatory stroke was the most prevalent, followed by the contralateral and reversed masticatory strokes. Miyauchi et al10 observed con-

significantly more anteriorly and inferiorly than did the

noncrossbite condyle.

and posterior. The mandible was also positioned asymmetrically relative to the cranial references, but the amount of asymmetry was smaller than that seen in the isolated mandible, suggesting that functional shifting

clear mandibular morphological asymmetry in children

with posterior unilateral crossbite. In their sample, the

mandible was significantly longer on the noncrossbite

side, and the molars and coronoid processes on the

crossbite side were located significantly more lateral

cave, crossover I, crossover II, and reverse types as the predominant patterns. Separate studies by Ben-Bassat et al⁶ and Brin et al⁷ also found high prevalences for the reverse-sequencing pattern in subjects with unilateral posterior crossbite. In their studies, the reversesequencing pattern occurred on the crossbite side more often than on the noncrossbite side. Orthodontic correction of the unilateral posterior crossbite with slow palatal expansion did not eliminate reverse sequencing in the chewing cycle, and those authors therefore speculated that skeletal asymmetry may have contributed to the unresolved reverse sequencing. However, they did not actually measure skeletal symmetry. The purpose of this study was to compare the pretreatment chewing cycles of unilateral crossbite patients with known skeletal asymmetry to controls, and to evaluate how rapid palatal expansion changed the masticatory cycles of the crossbite patients.

MATERIAL AND METHODS

The chewing pattern was examined in 14 patients with unilateral crossbite between 7 and 11 years of age. All were in the mixed dentition stage of dental development and exhibited functional unilateral posterior crossbites involving 3 or more posterior teeth. Nine patients had right crossbites, and 5 had left crossbites. The patients were age and gender matched with 14 controls recruited from family members of faculty and staff at Baylor College of Dentistry. The patients were selected on the basis of the presence of a posterior unilateral functional crossbite, mixed dentition, and no signs or symptoms of temporomandibular disorder. The controls were selected on the basis of the absence of a posterior unilateral functional crossbite, mixed dentition, and no signs or symptoms of temporomandibular disorder.

Each patient was treated with rapid palatal expansion for 2 to 4 weeks (2 turns per day, 0.25 mm per turn), followed by 6 months of retention. Before entering the study, informed consent was obtained from all subjects and their parents. Functional tests of mandibular motion were carried out before treatment and after 6 months of retention with the rapid palatal expander.

To measure mandibular motion, an intraoral splint was attached to each subject's lower teeth, and a mandibular rigid body with 4 light-emitting diodes was secured to the splint. A head rigid body with 6 light-emitting diodes attached to an eyeglass frame was secured to the subject's forehead with an elastic head strap. The head rigid body allowed the mandible to be tracked independently from head movements. The positions of tragus and orbitale were digitized bilaterally relative to the head rigid body to establish the Frankfort horizontal plane with a specially designed probe

(Northern Digital, Waterloo, Ontario, Canada). In addition, the contact point between the mandibular lower central incisor was digitized relative to the mandibular rigid body, and the position of this incisor point was tracked by the Optotrak optoelectric recording system (Northern Digital). The subject was seated in a comfortable upright position approximately 2 m in front of the Optotrak camera assembly and given a piece of chewing gum. The subject was allowed to chew the gum for 5 to 10 minutes to adapt to the intraoral splint. ¹²⁻¹⁴

Chewing gum was chosen to assess function because it forms a more consistent bolus than natural food, producing a consistent masticatory pattern over many cycles. ¹³ After the subjects became familiar with having the mandibular rigid body in place, they were instructed to place the gum on their tongue and to posture the mandible into maximum intercuspation; this position was recorded for 1 second, and then the subject was instructed to begin chewing normally. The number of chewing cycles was counted by an investigator, and the subject was asked to stop after approximately 20 cycles. The test was repeated with the subjects chewing for 20 cycles on the crossbite side only and then for 20 cycles on the noncrossbite side only.

As the subjects chewed, the 3-dimensional coordinates of the head and mandible rigid bodies were stored in the computer system. The data were preprocessed to subtract head movements from movements of the mandible and to relate movements of the incisor point to the Frankfort horizontal plane.

Data processing

Cycle duration and cycle shape were analyzed with the Optotrak optoelectrical system. A special computer program (written by H.H.) automatically identified the beginning of each cycle as the point where the chin marker reached its minimum opening. Details of this program and its use are presented elsewhere, 15 and the methods are briefly summarized here. The first cycle, during which the bolus is being moved from the top of the tongue to the occlusal table, was discarded from the analysis. Subsequent cycles were identified by the following criteria: (1) the minimum opening must be within ±4.0 mm of the baseline (the position of the incisor point before the subject started chewing), (2) each subsequent cycle must have a duration of at least 300 ms, and (3) each subsequent cycle must have a vertical opening of at least 3.0 mm. Cycles that did not meet these criteria were dropped from the analysis. The program next determined the coordinates of the incisor point at maximum lateral deviation during the closing phase of each cycle. If a cycle's incisor point was not located on the selected side during closing, that cycle was dropped from the analysis. Selection of cycles was carried out separately for each piece of gum for each subject.

The duration and maximum excursions in each remaining chewing cycle in each chewing sequence were determined, allowing the calculation of average cycle duration and mandibular excursions in the vertical, anteroposterior, and lateral directions for each sequence. Each cycle was given a standard score based upon its deviation from these averages, and the 10 cycles with the least deviation were selected as the best representatives for that chewing sequence. For each subject, further analysis was based on the 60 most representative cycles from the 3 chewing sequences (20 normal cycles, 20 on the crossbite side only, and 20 on the noncrossbite side only). A control's right and left side chewing cycles were considered to be either crossbite or noncrossbite, depending on whether the matched patient's crossbite was on the right or left side.

Another special computer program (also written by H.H.) calculated the duration of the total cycle, its opening and closing phases, maximum excursions (inferior, lateral, and posterior), total distance traveled by the chin marker in each cycle, and maximum velocities along each axis (vertical, lateral, and anteroposterior). ¹⁵ Overall cycle shape was evaluated by dividing the opening and closing phases into 40 equal parts based upon 5% increments of vertical movement of the chin marker. At each of these 40 points, the 3-dimensional coordinates of the incisor point were recorded for further analysis (Fig 1).

Multilevel linear models were used to generate an average cycle shape for each of the 3 chewing sequences. Multilevel modeling¹⁶⁻¹⁸ was also used to test for statistically significant differences in cycle duration, cycle shape, and cycle velocity at 4 levels: (1) between subjects, (2) between trials within subjects, (3) between cycles within trials, and (4) within cycles. 15 The fixed part of the model described the changes in jaw position with time. The entire masticatory cycle was described by an 8th-order polynomial. This procedure allowed evaluation of differences for the entire cycle; for example, differences in excursion were described by the constant term, differences in velocity were described by the first-order term, and differences in acceleration were described by the second-order term. These descriptions made it possible to evaluate the aspects of mastication that account for most of the variations. This approach provided several important advantages over existing methods, including objectivity, a more complete description of kinematic patterns, a hierarchical description of variation, and an ability to test the hypotheses statistically.

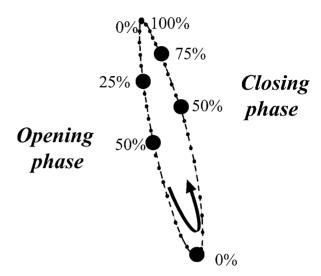


Fig 1. Diagramatic representation of plot of incisor pathway during chewing cycle. Each cycle is divided into 40 parts based on cycle duration (20 increments for opening phase and 20 increments for closing phase). Each point represents 5% of duration of that phase. Coordinates for all 3 axes are recorded for each point; however, only x and y coordinates are shown in this 2-dimensional plot.

RESULTS Chewing cycle duration

The results showed that cycle duration was significantly longer for the crossbite patients before treatment than it was for the controls (Table I). When the subjects chewed on the affected or crossbite side, the total cycle duration was approximately 140 ms longer for the crossbite patients. Similar differences in cycle duration (160 ms longer) were seen when the patients chewed on the noncrossbite side.

After treatment, cycle duration was significantly reduced in the crossbite patients (Table I) and was no longer significantly different from the control durations. Total cycle duration decreased by 160 ms with correction of the crossbite. Opening duration decreased by 90 ms, and closing duration decreased by 70 ms. A similar after-treatment reduction in cycle duration was observed on the noncrossbite side.

Maximum excursions

Before treatment, the patients averaged significantly greater inferior and posterior ranges of excursion than did the controls when chewing on either side (Table II). The patients' lateral ranges tended to be greater than those of the controls when chewing on the noncrossbite side and less than those of the controls when chewing on the crossbite side. Because the

Table I. Chewing cycle duration (mean \pm SE) before (T1) and after (T2) treatment (ms)

	Total cycle duration		Opening phase duration		Closing phase duration	
	Crossbite	Noncrossbite	Crossbite	Noncrossbite	Crossbite	Noncrossbite
Patients T1	849 ± 30*	817 ± 35*	440 ± 24*	404 ± 20*	409 ± 20*	413 ± 19*
Controls T1	$710 \pm 31*$	$656 \pm 22*$	$340 \pm 16*$	$315 \pm 11*$	$370 \pm 17*$	$341 \pm 16*$
Patients T2	687 ± 20	694 ± 27	349 ± 91	348 ± 14	338 ± 12	348 ± 14
Controls T2	691 ± 26	654 ± 20	334 ± 17	315 ± 11	357 ± 11	344 ± 92

^{*}Significant difference between patients and controls (P < .05).

Table II. Maximum cycle excursions (mean \pm SE) before (T1) and after (T2) treatment (mm)

	Inferior excursion		Posterior excursion		Lateral excursion		Total distance	
	Crossbite	Noncrossbite	Crossbite	Noncrossbite	Crossbite	Noncrossbite	Crossbite	Noncrossbite
Patients T1	10.7 ± 1.5*	13.2 ± 0.9*	6.0 ± 0.6 *	5.3 ± 0.5*	4.6 ± 0.4	5.8 ± 0.5	33.2 ± 2.9*	32.1 ± 2.1*
Controls T1	$11.4 \pm 1.0*$	$10.5 \pm 0.9*$	$3.4 \pm 0.3*$	$3.1 \pm 0.2*$	5.1 ± 0.6	5.1 ± 0.5	$27.1 \pm 2.3*$	$25.3 \pm 1.8*$
Patients T2 Controls T2	$15.2 \pm 1.5 \dagger$ $13.6 \pm 1.1 \dagger$	13.2 ± 0.9 14.1 ± 0.9 †	6.0 ± 1.0 4.4 ± 0.4 †	5.8 ± 0.9 5.8 ± 0.6 †	5.3 ± 0.7 5.8 ± 0.9	5.4 ± 0.7 5.8 ± 0.6	35.8 ± 3.7 32.3 ± 2.9 †	34.8 ± 3.7 32.9 ± 1.9 †

^{*}Significant difference between patients and controls (P < .05).

patients' inferior and posterior ranges were greater on the crossbite side and their lateral excursions were greater on the noncrossbite side, the total distances traveled by the incisors were nearly identical for each side and were significantly greater than the controls' total distances (Table II). Except for inferior excursions on the crossbite side, the patients showed little change in maximum excursions or the total distance of incisor travel after treatment, and their values remained significantly greater than the initial control values. However, the control subjects' inferior and posterior ranges were significantly greater before treatment than they were after treatment, resulting in a significant increase in their total distance of incisor travel. Therefore, after treatment, the patients and the controls did not differ significantly for any maximum excursion measurement.

Cycle kinematics—pretreatment noncrossbite side

Figure 2, A, shows a frontal view of the best-fit incisor pathways for the patients and the controls when chewing on the noncrossbite side. The y-axis represents inferior movement of the incisor point, and the x-axis represents lateral excursions toward the working side. The patients and the controls showed very similar patterns. During opening, the incisor first moved down and slightly toward the balancing side and then continued downward and toward the working side in a long elliptical loop. At maximum opening, the incisor point was about 3.5 mm toward the working side, and during clos-

ing the incisor moved through a long elliptical loop back to the starting point. The control subjects opened less widely than did the patients, but otherwise their incisor pathways were identical.

Figure 2, *B*, shows a superior view (the mandible from above) of the best-fit incisor pathways of these same cycles. The x-axis represents lateral excursion as before, but now the y-axis represents anteroposterior movement of the incisor point. During opening, in both patients and controls, the incisor moved in an elongated ellipse posteriorly and toward the working side during opening, and anteriorly and back to the starting point during closing. As seen in the frontal view, the patients had greater inferior and lateral excursions during these chewing cycles, but generally had the same cycle shape as had the controls.

Cycle kinematics—pretreatment crossbite side

Figure 3 shows frontal and superior views of the best-fit incisor pathways when patients and controls were chewing on the crossbite side. In both views, the patients demonstrated a reverse sequence in which the closing path crossed the opening path at about 3 mm inferior, 2 mm posterior, and 1 mm lateral to the starting position. In addition, the patient's chewing cycle was narrower, and the long axis of the cycle was closer to the midline than were the chewing cycles of the controls. As would be expected, the controls' cycles on the "crossbite" side were essentially the same as their cycles on the "noncrossbite" side.

[†]Significant change between T1 and T2 (P < .05).

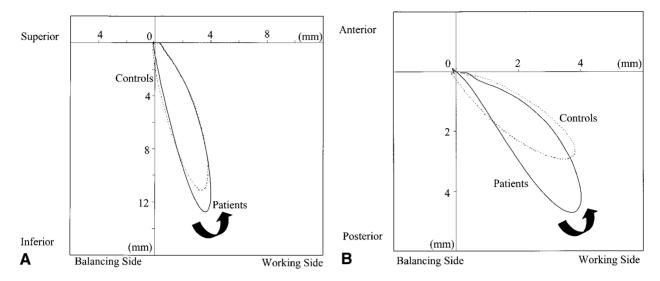


Fig 2. Best-fit plots of pretreatment incisor pathways of patients and controls when chewing on non-crossbite side. *Solid line* is incisor pathway for patients; *dashed line* is incisor pathway for controls. *Arrow* represents direction of jaw travel. **A**, Frontal view in which y-axis represents inferior movement and x-axis represents lateral excursion away from midline. **B**, Superior view in which y-axis represents posterior movement and x-axis represents lateral excursion.

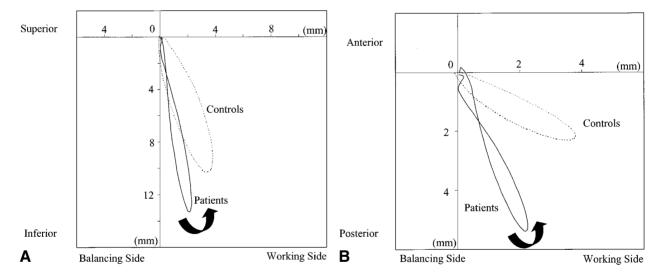


Fig 3. Best-fit plots of pretreatment incisor pathways of patients and controls when chewing on crossbite side. *Solid line* is incisor pathway for patients; *dashed line* is incisor pathway for controls. *Arrow* represents direction of jaw travel. **A**, Frontal view in which y-axis represents inferior movement and x-axis represents lateral excursion away from midline. **B**, Superior view in which y-axis represents posterior movement and x-axis represents lateral excursion.

Cycle kinematics—treatment effects

After treatment, there was very little change in cycle shape when subjects chewed on the noncross-bite side (Fig 4). Controls opened about 2 mm wider after treatment than they had before treatment, the pathway had a somewhat greater lateral excursion, and the axis of the cycle was a little closer to the

midline (Fig 4, A). Patients also opened about 2 mm wider after treatment, but otherwise their incisor pathway was identical to the pretreatment pathway (Fig 4, B). Because the patients' pretreatment pathway on the noncrossbite side was essentially normal, it is not surprising that treatment had little effect on it.

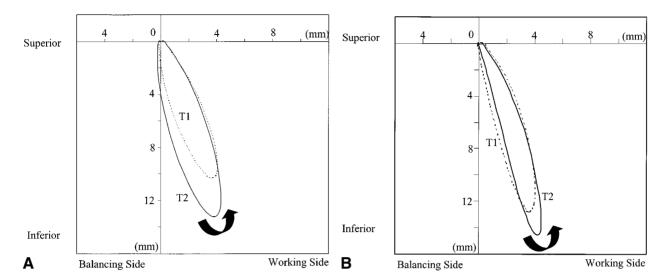


Fig 4. Frontal view of best-fit plots of pretreatment and posttreatment incisor pathways of patients and controls when chewing on noncrossbite side. *Dashed line* is incisor pathway at pretreatment stage, and *solid line* is incisor pathway at posttreatment stage. *Arrow* represents direction of jaw travel. **A**, Incisor pathways for control subjects at first (*dashed line*) and second (*solid line*) time intervals. **B**, Incisor pathways for patients before (*dashed line*) and after (*solid line*) treatment.

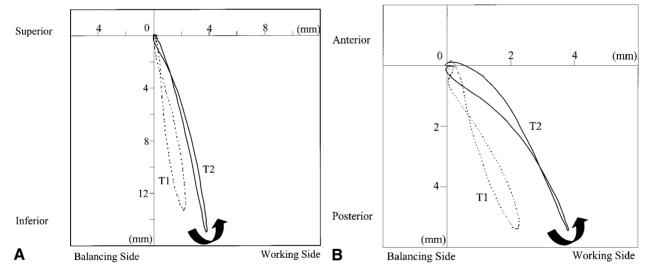


Fig 5. Best-fit plots of pretreatment and posttreatment incisor pathways of patients when chewing on crossbite side. *Dashed line* is pretreatment incisor pathway, and *solid line* is posttreatment incisor pathway. *Arrow* represents direction of jaw travel. **A**, Frontal view in which y-axis represents inferior movement and x-axis represents lateral excursion away from midline. **B**, Superior view in which y-axis represents posterior movement and x-axis represents lateral excursion.

The patients' chewing cycle on the crossbite side also showed relatively little change with treatment (Fig 5). The reverse sequence was still present, although the crossing point was located more laterally and farther posteriorly than before treatment. The chewing cycle remained quite narrow (medial to lateral), although the position of the incisors at maximum opening had

shifted significantly laterally (from 2 mm toward the working side to 4 mm toward the working side).

DISCUSSION

Both the patients and the control subjects tended to open more widely (Fig 4) at the second recording session. The reason for this change is not clear. Although there might have been some increase in mandibular length over the 6-month study period, it seems unlikely that the amount of growth was sufficient to produce the observed changes. It is possible that the children were more comfortable in the recording environment at the second session, resulting in less-constrained excursions during chewing.

It is well established that children with unilateral posterior crossbites tend to have abnormal chewing patterns, often characterized by reverse sequencing. 6,7,9,10,14,19 Reverse sequencing occurs more frequently when chewing on the crossbite side and on harder foods. Presently, the reason for the development of the reverse-sequencing pattern on the crossbite side is not clearly understood. The pattern may be necessary to align the working surfaces of the crossbite-aligned teeth as they move into the occlusal phase. Because the pattern appears so early, longitudinal studies of children's masticatory patterns during the development of their primary dentition would be needed to determine the exact mechanism.

In a cross-sectional study, Ben-Bassat et al⁶ found that crossbite patients, treated with slow palatal expansion, had a lower incidence of chewing cycles with reverse sequencing (18.4%) than did untreated patients (38.8%). But this incidence of reverse sequencing was still higher than it was in the controls (12.8%). In 1996, this same group used a longitudinal study to confirm that successful treatment of the crossbite with slow palatal expansion did not eliminate the reverse sequencing chewing patterns. They speculated that the unresolved reverse sequencing pattern was the result of skeletal asymmetry, either present when the functional shift was initially diagnosed or developing during treatment with slow palatal expansion.

Our study indicated that skeletal asymmetry was already present at the initial diagnosis. A morphological study of these patients before treatment and testing found a longer mandibular ramus on the noncrossbite side. In addition, the treatment used here, rapid palatal expansion, would not leave enough time for a secondary asymmetry to develop.

At first, it might seem surprising that eliminating unilateral posterior crossbite would normalize chewing cycle duration but not eliminate the reverse-sequencing pattern. However, our results are consistent with the concept that mandibular kinematics during chewing are controlled at more than 1 level. ^{20,21} At 1 level is the central pattern generator. ^{22,23} This pattern generator appears to establish cycle shape, perhaps by controlling the sequence of contractions of the opening and closing musculature. Specific cycle shape is established during initial eruption of the primary dentition. ²⁴⁻²⁸ and dis-

rupting the primary dentition before eruption can delay the development of normal chewing patterns.²⁸

However, once cycle shape has been established in the central pattern generator, it appears to be relatively resistant to change. Studies in children suggest that the amount of lateral excursion during opening and closing gradually changes as the primary dentition is replaced by the permanent dentition, but otherwise the overall cycle shape is maintained.^{24,25} Studies in adults have been unable to show consistent changes in overall cycle shape either after adding occlusal interferences^{29,30} or removing them.³¹ Studies in animals indicate that, even after severe disruptions of sensory input from the jaws^{32,33} or motor innervation of the jaw muscles,^{21,34,35} cycle shape remains largely unaltered.

Perhaps most significant is the maintenance of the "butterfly" pattern of chewing cycles in guinea pigs. The "butterfly" pattern is similar to the reverse-sequencing pattern of crossbite patients in that the incisor's opening pathway crosses its closing pathway. Even after cerebellar ablation³⁴ or unilateral lesioning of the trigeminal motor nucleus, ²¹ guinea pigs maintained the "butterfly" chewing pattern.

The second level of control may be more peripheral and appears to be much more sensitive to sensory input. This peripheral level responds to interferences by slowing or even stopping the chewing cycle and by lowering the amount of occlusal force used during mastication. 30,36-40 Increases in cycle duration occur after loss of sensory input 33,41-43 or after disruption of motor innervation. 21,35 Cycle duration is also longer in young animals before eruption of the adult dentition. 26,27,44,45

Because unilateral posterior crossbite develops during eruption of the primary dentition, it has a powerful influence on the developing central pattern generator, establishing the reverse-sequencing type of chewing pattern. The unilateral posterior crossbite also includes an interference, and the peripheral control system responds by slowing the chewing cycle. After orthodontic treatment has removed the interference, the peripheral system acts to normalize the chewing-cycle duration, perhaps by removing an inhibition on the central pattern generator. On the other hand, because the central pattern generator is more resistant to change, eliminating the crossbite has much less effect on the reverse-sequencing pattern.

CONCLUSIONS

Before treatment, cycle duration was significantly longer in crossbite patients than it was in controls when chewing on both the affected and nonaffected sides. The patients' opening phases were longer than those of the controls when chewing on the crossbite side.

After treatment, there were no significant differences in cycle duration between the controls and the crossbite patients.

Before treatment, the crossbite patients showed greater cycle anteroposterior and vertical excursions than did the controls.

Before treatment, the crossbite patients showed fewer lateral excursions than did the controls and a reverse sequence of mastication while chewing on the affected side.

After treatment, maximum excursions were unchanged in the crossbite patients, and they still maintained a reverse sequence of mastication.

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